#11/Decl.

PATENT
Attorney Docket No.: 020921-001110US

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re application of: VICTOR B. KLEY Application No.: 10/047,454 Filed: January 14, 2002 For: SCANNING PROBE MICROSCOPE ASSEMBLY AND METHOD FOR MAKING SPECTROPHOTOMETRIC, NEAR-FIELD, AND SCANNING PROBE MEASUREMENTS	Examiner: Thanh X Luu Art Unit: 2878 DECLARATION OF VICTOR B. KLEY UNDER 37 C.F.R. § 1.131

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

I, Victor B. Kley, declare as follows:

1. I am the inventor of the present patent application. The present application is a continuation of U.S. Patent Application No. 08/776,361, filed May 16, 1997, now U.S. Patent No. 6,339,217, issued January 15, 2002, which is a National Phase filing of PCT Application No. PCT/US95/09553, filed July 28, 1995 (Pub. WO 96/03641), which is a continuation-in-part of U.S. Patent Application No. 08/412,380, filed March 29, 1995, now abandoned, which is a continuation-in-part of U.S. Patent Application No. 08/281,883, filed July 28, 1994, now abandoned ("the '883 application").

2. I have read and understand the claims currently pending in the present application.

3. I conceived my invention in the United States before April 11, 1994.

4. The following represents events that led up to the filing of the '883 application on July 28, 1994. All events referenced below took place in the United States.

<u>Conception and Development Work</u>

5. Before April 11, 1994, I began working on new methods for increasing the durability and sharpness of atomic force microscopes (AFMs) and scanning tunneling microscopes

(STMs), and worked with researchers at the University of California at Berkeley (UCB) and Lawrence Berkeley National Labs (LBNL), who were involved in plasma deposition of diamond and silicon carbide, to make tests of my ideas for diamond coating or initiating diamond growth on AFM or STM tips.

6. Before April 11, 1994, I conceived techniques for building an AFM or STM on a MEMS accelerometer base design developed by Professor Albert P. Pisano of UCB and began discussions with him and UC.

7. Before April 11, 1994, as part of this effort and my long-term ongoing interest (from 1979) in molecular identification (particularly of the nucleotides, oligonucleotides, and other components of DNA), I conceived of techniques for combining spectrophotometry with AFM and/or STM in one scanning probe microscope (SPM) system.

8. Before April 11, 1994, I approached Technical Instruments Corporation (TIC), a local firm, for backing in these endeavors. With TIC's help I began development of hardware and software with my Metadigm development group.

<u>Work with Edward Morse (Exhibits A, B, and C)</u>

9. Before April 11, 1994, I engaged Professor Edward C. Morse of UCB to help analyze some of the electromagnetic properties of the invention, and he provided a series of reports on a weekly basis (both oral and written) on this subject from before April 11, 1994 and continuing through after April 11, 1994.

<u>Work in Getting the '883 Application Prepared and Filed (Exhibit D)</u>

10. Before April 11, 1994, I arranged through TIC to use its patent attorney, Aldo Test at the firm of Flehr, Hohbach, Test, Albritton & Herbert ("the Flehr firm"), to work with me and prepare a patent application on my invention. I was assigned an associate, Stephen M. Knauer, at the Flehr firm to work on my patent application

11. Before April 11, 1994, I met with Mr. Knauer, and in our earliest conversations (possibly before our first meeting), I asked Mr. Knauer to let me write a structured detailed disclosure of the invention. This would ensure that Mr. Knauer had information on all the embodiments, and was further intended to reduce the amount of time (and attendant legal fees) he would need to write a comprehensive disclosure. This was a practice that I had

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successfully used with a number of patent attorneys over the previous decade of patent filings.

12. I provided technical information regarding the invention to Mr. Knauer during our meetings and telephone conversation, as well as via the internet (Compuserve) and floppy disks sent through the mail. This allowed him to draft the patent application, leading up to the filing of the '883 application on July 28, 1994.

13. From before April 11, 1994, until at least July 28, 1994, I worked to provide necessary information and feedback to Mr. Knauer to facilitate and expedite that preparation and filing of the '883 application.

Exhibits

14. The following are Exhibits to this Declaration:

- Exhibit A — (i) An undated report by Professor Morse reflecting work he had done in connection with the invention;
  (ii) A text printout of a file named DIAMOND4.TXT (the document is in the T_EX markup language) from Professor Morse's hard drive reflecting a save date of April 17, 1994; and
  (iii) A printout of the DIAMOND4.TXT file as translated to from T_EX to HTML at a later date, reflecting that the file corresponds to the undated report.
- Exhibit B — (i) A text printout of a file named DIAMOND3.TXT (the document is in the T_EX language) from Professor Morse's hard drive reflecting a save date of February 17, 1994; and
  (ii) A printout of the DIAMOND3.TXT file as translated from T_EX to HTML at a later date.
- Exhibit C — A text printout of a file named POLYROD.BAS from Professor Morse's hard drive reflecting a save date of March 17, 1994. This file is a Basic program that is believed to have been used in connection with generating a graph attached to the undated report of Exhibit B.
- Exhibit D — Billing records from the Flehr firm reflecting a meeting with Mr. Knauer before April 11, 1994, work by Mr. Knauer after our meeting but before

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April 11, 1994, and work by Mr. Knauer in drafting the patent application during the May-July 1994 time period.

I hereby declare that all statements made herein of my own knowledge are true, that all statements made herein on information and belief are believed to be true, and further that these statements were made with the knowledge that willful false statements and the like are punishable by fine or imprisonment, or both; under 18 U.S.C. 1001, and that such willful false statements and the like may jeopardize the validity of this application or any patent issuing thereon.

Signed: ______________________ Dated: 7/06/03
Victor B. Kley

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Optical Transmission in Diamond AFM Tips

EDWARD C. MORSE

1. PURPOSE OF REPORT

A refinement of the atomic force microscope (AFM) has been proposed by Victor Kley. This refinement is to provide a secondary imaging system using the AFM's tip as a light-transmitting element when it is in close proximity to the surface being studied. Whereas some AFM tips are small in terms of a visible or infrared wavelength (such as diamond tips), there is nevertheless some possibility of imaging due to the near-field effects of reflections occurring from a surface inside the evanescent zone. Furthermore conventional materials such as silicon, silicon carbide, and silicon nitride are also used as AFM tips, and these can be large in wavelengths.

The purpose of this report is to evaluate this invention from principles of applied optics and electromagnetic theory. The possibility of light transmission through small AFM tips is addressed in this report, and some possible schemes for exploiting this phenomenon which have been put forward by Kley are evaluated here.

1. ANALYSIS

Tips for atomic force microscopes can be made from diamond, silicon, silicon carbide, and other materials. A typical plasma discharge-grown diamond crystal has a size of about 70 nm and is thus is a small fraction of a visible light wavelength, which is on the order of 700 nm (red) to 450 nm (blue). Infrared wavelengths from IR laser diodes in the 940 nm range are also of interest, as are quartz UV photons with wavelengths as short as 175 nm. Thus this crystal size represents a size from about $0.07\lambda_0 \rightarrow 0.4\lambda_0$ depending on the type of radiation used. It is important to note that the relatively high index of refraction in diamond (2.4) results in the crystal size in units of wavelength in diamond to be larger: the 70 nm size thus represents a range in wavelength dimensions of $0.17\lambda_D \rightarrow 1.0\lambda_D$, where $\lambda_D = \lambda_0/n$, where n is the index of refraction. Silicon tips tend to be physically larger with steeper sides. Silicon tips may be as large as $10\lambda \times 10\lambda$ on base and as high as 40λ.

The transmission of light from AFM tips of this kind can be modeled using antenna theory. We assume that the light is coupled to the tip via a waveguide structure of some sort. Losses in this waveguide structure can be kept low by careful design. If the waveguide is physically small, e. g. a few wavelengths on a side, we can model the tip as being the antenna transition from this dielectric waveguide. The waveguide structure will typically have an index of refraction lower than that of the tip (for example, a fused silica waveguide with $n = 1.45$ and a diamond tip with $n = 2.4$), and thus some matching may be required to optimize the coupling into the tip.

The first step in analyzing the performance of the tip as an optical launching structure is to examine the antenna gain and radiation pattern of this structure as a function of the size in wavelengths of the object. As a starting point, we assume a fundamental TE-mode excitation from the base of the tip. We use a Fresnel-Huygens method similar to that employed by Schelkunoff[1] for calculation of antenna patterns, but modified by the presence of a dielectric medium with index n, which affects the phase retardation term inside the crystal. This general technique is outlined in a paper by Watson and Horton[2], who applied the method to an analysis of dielectric rods (called polyrods) for military radar. In this paper, they assumed that a TE-like fundamental mode from a waveguide excited a tapered dielectric rod which was pyramidal in shape and was a fraction of a wavelength in thickness. The fields at the base of the pyramid (size $a \times b$) are then:

$$\begin{aligned}
\vec{E}_{0,1} &= \hat{x}\cos(\pi y/b)\exp\big(-j(\omega t - k'z)\big), \\
\vec{H}_{0,1} &= \{\hat{y}(k'/\omega\mu)\cos(\pi y/b) + \hat{z}(\pi/j\omega\mu b)\sin(\pi y/b)\}\exp\big(-j(\omega t - k'z)\big).
\end{aligned}$$

The Fresnel method then prescribes magnetic currents on the two E-plane sides of the magnetic structure and electric currents on the two H-plane sides. The far-field radiation is then found by a straightforward integration of these Fresnel integrals. Adopting spherical geometry, with the $\hat{z}$ axis corresponding to $\theta = 0$, the following fields are obtained:

$$\begin{aligned}
E_r &= 0, \\
E_\theta &= (jk\cos\phi)P_1(\theta,\phi), \\
E_\phi &= (-jk\sin\phi\cos\theta)P_1(\theta,\phi).
\end{aligned}$$

Here the function $P_1(\theta,\phi)$ is given by:

$$P_1(\theta,\phi) = M_0\cos\left[(ka/2)\sin\theta\cos\phi\right]\cdot I_1\cdot I_2$$

where the functions I_1 and I_2 are given by

$$\begin{aligned}
I_1 &= \frac{2b}{\pi}\frac{(\pi/2)^2\cos\left((kb/2)\sin\theta\sin\phi\right)}{(\pi/2)^2 - \left((kb/2)\sin\theta\sin\phi\right)^2}, \\
I_2 &= \frac{1}{2k}(A - jB), \\
A &= \frac{1}{n-\cos\theta}\left[1-\cos\{(n-\cos\theta)kl\}\right] \\
&\quad + \frac{1}{n+\cos\theta}\left[1-\cos\{(n+\cos\theta)kl\}\right] \\
B &= \frac{\sin\{(n-\cos\theta)kl\}}{n-\cos\theta} - \frac{\sin\{(n+\cos\theta)kl\}}{n+\cos\theta}
\end{aligned}$$

Here $n = k'/k$, and l is the length of the crystal in the $\hat{z}$ direction .

In the above analysis, the quantity M_0 is a normalization which relates the intensity of the antenna source to the electric field in the waveguide.

It is relatively straightforward to evaluate these expressions for a field pattern from tetrahedral radiator. A number of such field patterns for various sizes of crystals are shown in the attached plots. Notice that since a TE-mode excitation is assumed, the general two-dimensional pattern is not symmetric in rotation of the coordinate system by 90 degrees. Thus both E-plane and H-plane angular plots are included here. In general, the pattern in these two planes is different, even when the base sides are equal in length. This characteristic may be exploited in the AFM imaging system: by varying the excitation mode at the base of the crystal, different two-dimensional patterns could be excited, leading to the possibility of higher resolution upon unfolding. These polar plots have the gain normalized to show the maximum gain as 0 decibels. The maximum gain (relative to a unit dipole radiator) used as a normalizing factor is indicated on each plot.

The field model presented here uses the assumption that the phase retardation of the impressed fields on the surfaces of the crystal is that due to the phase delay of an electromagnetic wave traveling through the crystal. As the wave propagates partially in free space, the actual phase velocity will be faster, particularly in radiation geometries which are long in the z-direction. A more accurate model may thus be made by using an effective index of refraction which is smaller than the index of the material but larger than unity. This modification is easy to perform in the numerical analysis, and the effect of lowering the effective dielectric constant is easily seen. For a diamond crystal with a 1.0λ height, this lowering of the effective dielectric constant results in a concentrated beam of radiation into a sixty degree cone, whereas it is broadcast over 2π sterradians in the $n = 2.4$ case. With a full wavelength in height, the lower dielectric case is probably more representative of the real situation, whereas for the smaller crystals with less overall gain, the effective index is probably closer to the real index of refraction in the diamond. Examples are also included for larger, steeper crystals such as might be fabricated from silicon, for example. For these larger sizes, the method produces realistic results if the dielectric constant is held close to unity even if the internal dielectric constant is high, since the crystal becomes a surface wave transducer with an HE-like mode. In general, as crystal size becomes larger and the sides become steeper, gain increases and directivity becomes higher. However, the assumption that the amplitude and phase on the faces are not affected by radiation is made in this model, and thus the results become less accurate as the size increases. Ref. 3 indicated that experimental polyrod antennae showed behavior similar to the model in sizes up to about 6λ. For larger sizes than that, the model showed the qualitative properties of the actual device, but tended to overestimate the gain and directivity somewhat. Polyrod antennae of up to 20λ have actually been constructed and tested, and show the same general features experimentally.

2. CONCLUSIONS

The results of this study show that structures as small as 0.28 wavelengths on a side

can act as credible radiators of optical energy. Efficiency increases in general towards larger sizes. A highly efficient, directive radiator results if the transverse dimensions of the crystal are kept small but the height is several wavelengths. A crystal of this type might be possible by ion milling, for example. The broad patterns resulting from small crystals may be useful where the distance to a nearby scatterer is small and the scatterer has a large optical cross section.

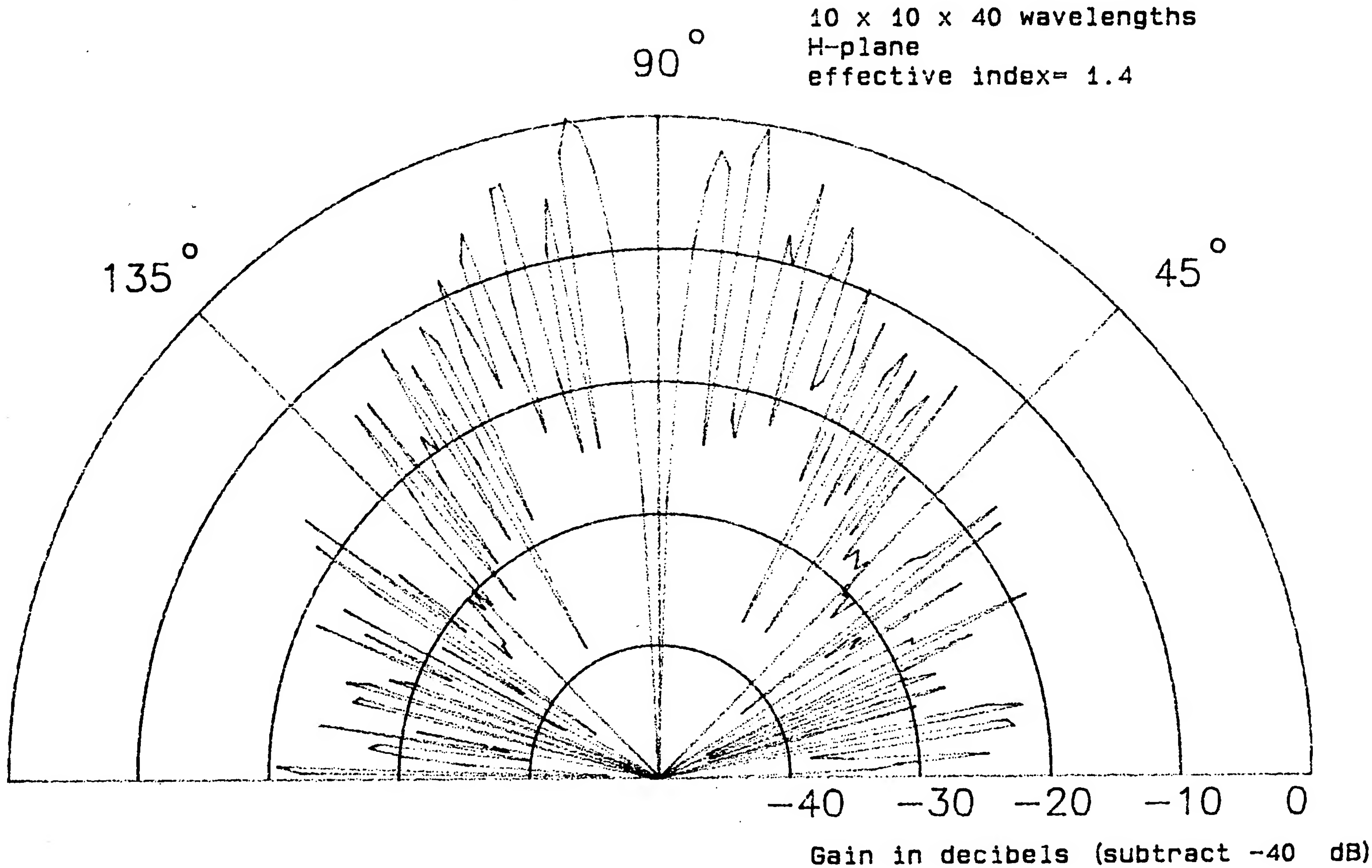
One can envision two widely different applications of this method. With long crystals and UV light, an efficient pencil-beam optical scanner might be useful using specially milled crystals. For small crystals, The broad pattern might be useful for identification of nearby molecules on the surface with certain resonance characteristics. Here optical drive power must be kept high enough to overcome the losses from the launcher, but the small sizes may allow mechanical scanning to work with some accuracy.

Issues remaining to be resolved are the coupling between the base of the AFM tip crystal and the external optical system and the physics of light coupling in the near field. The coupling mechanism is modeled here as a TE-mode coupling to an optical waveguide. This might not be the most desirable coupling, nor one which is easily constructed on a silicon substrate. Other coupling geometries might lead to different pattern geometries and might have substantially different optical gain. The near-field properties are likely to be important if imaging at distances below $\lambda/6$, i. e. about 30 nm at UV wavelengths, is anticipated. The high index of diamond, however, mitigates these effects somewhat. The problem of resonant molecules in the near field is an important one for this application, and here the coupling might be strong enough to affect the retarded fields on the diamond's surfaces and merit another analytical approach.

3. References

1. S. A. Schelkunoff, *Electromagnetic Waves*, Van Nostrand, New York, 1943.
2. R. B. Watson and C. W. Horton, *J. Appl. Phys.* **19**, 661 (1948).
3. G. E. Mueller and W. A. Tyrell, *Bell Syst. Tech. Jour.* 27, 837 (1948).

Polar Directivity Plot



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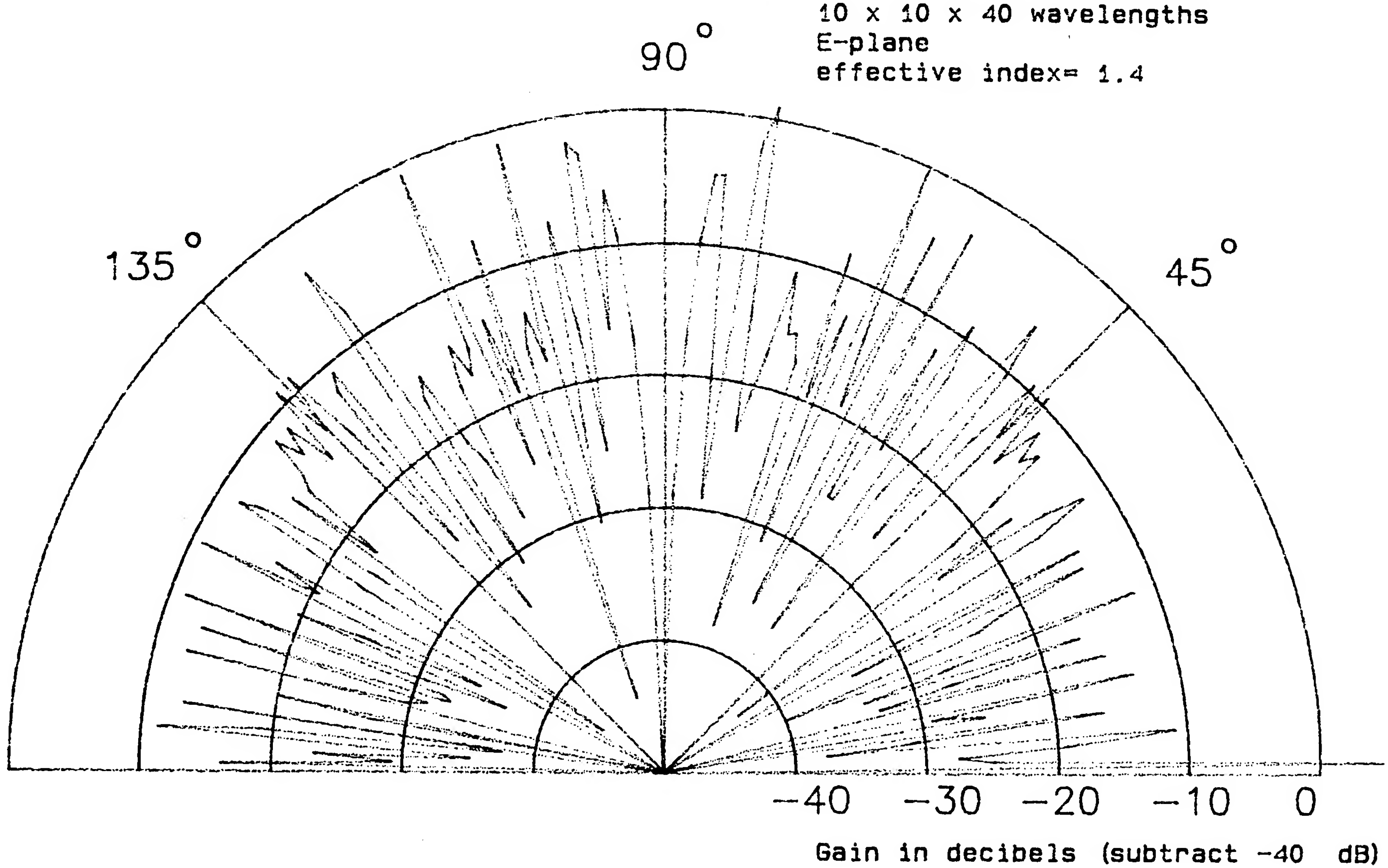

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Optical Transmission in Diamond AFM Tips\\
\endtitle
\author
Edward C. Morse
\endauthor
\heading

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\item{1.} S. A. Schelkunoff, {\sl Electromagnetic Waves}, Van Nostrand, New
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\item{2.} R. B. Watson and C. W. Horton, {\sl J. Appl. Phys.} {\bf 19}, 661
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\item{3.} G. E. Mueller and W. A. Tyrell, {\sl Bell Syst. Tech. Jour.} {27}, 837
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Content-type: text/HTML

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Edward C. Morse

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Tips for atomic force microscopes can be made from diamond, silicon, silicon carbide, and other materials. A typical plasma discharge-grown diamond crystal has a size of about 70 nm and is thus is a small fraction of a visible light wavelength, which is on the order of 700 nm (red) to 450 nm (blue). Infrared wavelengths from IR laser diodes in the 940 nm range are also of interest, as are quartz UV photons with wavelengths as short as 175 nm. Thus this crystal size represents a size from about 0.07 λ_0 $\rightarrow$ 0.4 λ_0 depending on the type of radiation used. It is important to note that the relatively high index of refraction in diamond (2.4) results in the crystal size in units of wavelength in diamond to be larger: the 70 nm size thus represents a range in wavelength dimensions of 0.17 $\lambda_D \rightarrow$ 1.0 λ_D, where $\lambda_D=\lambda_0 / n$, where n is the index of refraction. Silicon tips tend to be physically larger with steeper sides. Silicon tips may be as large as 10 $\lambda\times$10 λ on base and as high as 40 λ.

The transmission of light from AFM tips of this kind can be modeled using antenna theory. We assume that the light is coupled to the tip via a waveguide structure of some sort. Losses in this waveguide structure can be kept low by careful design. If the waveguide is physically small, e. g. a few wavelengths on a side, we can model the tip as being the antenna transition from this dielectric waveguide. The waveguide structure will typically have an index of refraction lower than that of the tip (for example, a fused silica waveguide with n=1.45 and a diamond tip with n=2.4), and thus some matching may be required to optimize the coupling into the tip.

The first step in analyzing the performance of the tip as an optical launching structure is to examine the antenna gain and radiation pattern of this structure as a function of the size in wavelengths of the object. As a starting point, we assume a fundamental TE-mode excitation from the base of the tip. We use a Fresnel-Huygens method similar to that employed by Schelkunoff[1] for calculation of antenna patterns, but modified by the presence of a dielectric medium with index n, which affects the phase retardation term inside the crystal. This general technique is outlined in a paper by Watson and Horton[2], who applied the method to an analysis of dielectric rods (called polyrods) for military radar. In this paper, they assumed that a TE-like fundamental mode from a waveguide excited a tapered dielectric rod which was pyramidal in shape and was a fraction of a wavelength in thickness. The fields at the base of the pyramid (size a $\times$b) are then:

$$\vec{E}_{0,1} = \hat{x}\cos(\pi y / b) \exp\left(-j (\omega t - k' z)\right),$$

$$\vec{H}_{0,1} = \left\{ \hat{y} (k'/ \omega\mu) \cos(\pi y / b) + \hat{z} (\pi / j \omega\mu b) \sin(\pi y /b) \right\} \exp\left(-j(\omega t - k'z) \right).$$

The Fresnel method then prescribes magnetic currents on the two E-plane sides of the magnetic structure and electric currents on the two H-plane sides. The far-field radiation is then found by a straightforward integration of these Fresnel integrals. Adopting spherical geometry, with the [^z] axis corresponding to θ = 0, the following fields are obtained:

$$E_r = 0,$$
$$E_\theta = (jk \cos\phi) P_1(\theta,\phi),$$
$$E_\phi = (-jk \sin\phi\cos\theta) P_1(\theta,\phi).$$

Here the function $P_1(\theta, \phi)$ is given by:

$$P_1(\theta, \phi) = M_0 \cos[(ka/2) \sin\theta\cos\phi] \cdot I_1 \cdot I_2$$

where the functions I_1 and I_2 are given by

$$I_1 = \frac{2b}{\pi} \frac{(\pi / 2)^2 \cos((k b / 2) \sin\theta\sin\phi)}{(\pi / 2)^2 - ((k b / 2) \sin\theta\sin\phi)^2},$$

$$I_2 = \frac{1}{2k}(A - jB),$$

$$A = \frac{1}{n - \cos\theta}[1 - \cos\{(n - \cos\theta) kl \}] + \frac{1}{n + \cos\theta}[1 - \cos\{(n + \cos\theta) kl \}]$$

$$B = \frac{\sin\{(n - \cos\theta) kl \}}{n - \cos\theta} - \frac{\sin\{(n + \cos\theta) kl \}}{n + \cos\theta}$$

Here $n = k'/ k$, and l is the length of the crystal in the [^z] direction .

In the above analysis, the quantity M_0 is a normalization which relates the intensity of the antenna source to the electric field in the waveguide.

It is relatively straightforward to evaluate these expressions for a field pattern from tetrahedral radiator. A number of such field patterns for various sizes of crystals are shown in the attached plots. Notice that since a TE-mode excitation is assumed, the general two-dimensional pattern is not symmetric in rotation of the coordinate system by 90 degrees. Thus both E-plane and H-plane angular plots are included here. In general, the pattern in these two planes is different, even when the base sides are equal in length. This characteristic may be exploited in the AFM imaging system: by varying the excitation mode at the base of the crystal, different two-dimensional patterns could be excited, leading to the possibility of higher resolution upon unfolding. These polar plots have the gain normalized to show the maximum gain as 0 decibels. The maximum gain (relative to a unit dipole radiator) used as a normalizing factor is indicated

on each plot.

The field model presented here uses the assumption that the phase retardation of the impressed fields on the surfaces of the crystal is that due to the phase delay of an electromagnetic wave traveling through the crystal. As the wave propagates partially in free space, the actual phase velocity will be faster, particularly in radiation geometries which are long in the z-direction. A more accurate model may thus be made by using an effective index of refraction which is smaller than the index of the material but larger than unity. This modification is easy to perform in the numerical analysis, and the effect of lowering the effective dielectric constant is easily seen. For a diamond crystal with a 1.0 λ height, this lowering of the effective dielectric constant results in a concentrated beam of radiation into a sixty degree cone, whereas it is broadcast over 2 π sterradians in the n=2.4 case. With a full wavelength in height, the lower dielectric case is probably more representative of the real situation, whereas for the smaller crystals with less overall gain, the effective index is probably closer to the real index of refraction in the diamond. Examples are also included for larger, steeper crystals such as might be fabricated from silicon, for example. For these larger sizes, the method produces realistic results if the dielectric constant is held close to unity even if the internal dielectric constant is high, since the crystal becomes a surface wave transducer with an HE-like mode. In general, as crystal size becomes larger and the sides become steeper, gain increases and directivity becomes higher. However, the assumption that the amplitude and phase on the faces are not affected by radiation is made in this model, and thus the results become less accurate as the size increases. Ref. 3 indicated that experimental polyrod antennae showed behavior similar to the model in sizes up to about 6 λ. For larger sizes than that, the model showed the qualitative properties of the actual device, but tended to overestimate the gain and directivity somewhat. Polyrod antennae of up to 20 λ have actually been constructed and tested, and show the same general features experimentally.

2. Conclusions

The results of this study show that structures as small as 0.28 wavelengths on a side can act as credible radiators of optical energy. Efficiency increases in general towards larger sizes. A highly efficient, directive radiator results if the transverse dimensions of the crystal are kept small but the height is several wavelengths. A crystal of this type might be possible by ion milling, for example. The broad patterns resulting from small crystals may be useful where the distance to a nearby scatterer is small and the scatterer has a large optical cross section.

One can envision two widely different applications of this method. With long crystals and UV light, an efficient pencil-beam optical scanner might be useful using specially milled crystals. For small crystals, The broad pattern might be useful for identification of nearby molecules on the surface with certain resonance characteristics. Here optical drive power must be kept high enough to overcome the losses from the launcher, but the small sizes may allow mechanical scanning to work with some accuracy.

Issues remaining to be resolved are the coupling between the base of the AFM tip crystal and the external optical system and the physics of light coupling in the near field. The coupling mechanism is modeled here as a TE-mode coupling to an optical waveguide. This might not be the most desirable coupling, nor one which is easily constructed on a silicon substrate. Other coupling geometries might lead to different pattern geometries and might have substantially different optical gain. The near-field properties are likely to be important if imaging at distances below $\lambda/6$, i. e. about 30 nm at UV wavelengths, is anticipated. The high index of diamond, however, mitigates these effects somewhat. The problem of resonant molecules in the near field is an important one for this application, and here the coupling might be strong enough to affect the retarded fields on the diamond's surfaces and merit another analytical approach.

3. References

1. S. A. Schelkunoff, *Electromagnetic Waves*, Van Nostrand, New York, 1943.
2. R. B. Watson and C. W. Horton, *J. Appl. Phys.* **19**, 661 (1948).
3. G. E. Mueller and W. A. Tyrell, *Bell Syst. Tech. Jour.* 27, 837 (1948).

File translated from T_EX by T_TH, version 3.40.
On 12 Jun 2003, 10:49.

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\input vanilla.sty
\scaletype{\magstep1}
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\title
Near-Field Optics in Diamond AFM Tips:\\
A Progress Report\\
\endtitle

A proposed refinement of the atomic force microscope (AFM) is to provide a
secondary imaging system
using the AFM's diamond tip as a light-transmitting element when it is in close
proximity to the surface being studied.
Although the AFM tip size is typically small in terms of  a visible or infrared
wavelength, there
is nevertheless some possibility of imaging due to the near-field effects of
reflections occurring from a surface
inside the evanescent zone.  A preliminary analysis of a possible configuration
is given here.

Suppose that a pyramidal diamond is mounted on a dielectric launcher of some
sort. We suppose that an optical wave is launched towards the tip of the
diamond from the base. At some point the cross-sectional area of the diamond tip
is below the cutoff for the fundamental mode of propagation, which
would be a $HE_{11}$-like mode. (If the base of the diamond is less than a
half-wavelength in the dielectric medium, propagation may be completely
evanescent.)
The propagation can be modeled as the propagation of a mode in a leaky, tapered,
dielectric waveguide. Some insight into the solutions can be
seen from using a conical geometry to approximate the diamond tip.
Electromagnetic wave solutions to this type
of problem exist: they are given by Airy functions, which are related to
modified Bessel functions of
order $1/3$. The associated evanescent field external to the waveguide is found
by matching boundary conditions,
and scattering from the surface can be treated as an additional matching
condition.

A reciprocity theorem can be used to calculate the overall gain (loss) of the
optical system. Since
the field is evanescent, it is likely that the geometry of the surface plays a
greater role than the absorption.
In general, the evanescent fields will be of longer spatial extent at longer
wavelengths, but phase information will be reduced,
and return signals will be of lower quality.
\vfill \end
```

Content-type: text/HTML

Near-Field Optics in Diamond AFM Tips:
A Progress Report

A proposed refinement of the atomic force microscope (AFM) is to provide a secondary imaging system using the AFM's diamond tip as a light-transmitting element when it is in close proximity to the surface being studied. Although the AFM tip size is typically small in terms of a visible or infrared wavelength, there is nevertheless some possibility of imaging due to the near-field effects of reflections occurring from a surface inside the evanescent zone. A preliminary analysis of a possible configuration is given here.

Suppose that a pyramidal diamond is mounted on a dielectric launcher of some sort. We suppose that an optical wave is launched towards the tip of the diamond from the base. At some point the cross-sectional area of the diamond tip is below the cutoff for the fundamental mode of propagation, which would be a HE_{11}-like mode. (If the base of the diamond is less than a half-wavelength in the dielectric medium, propagation may be completely evanescent.) The propagation can be modeled as the propagation of a mode in a leaky, tapered, dielectric waveguide. Some insight into the solutions can be seen from using a conical geometry to approximate the diamond tip. Electromagnetic wave solutions to this type of problem exist: they are given by Airy functions, which are related to modified Bessel functions of order 1/3. The associated evanescent field external to the waveguide is found by matching boundary conditions, and scattering from the surface can be treated as an additional matching condition.

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File translated from $\TeX$ by T_TH, version 3.40.
On 12 Jun 2003, 10:51.

```
2 DIM gain(180)
10 PRINT "input length in wavelengths"
20 INPUT l
30 PRINT "input side a in wavelengths"
40 INPUT a
50 PRINT "input side b in wavelengths"
60 INPUT b
61 OPEN "com1:4800,n,8,1,rs,cs65535,ds,cd" FOR RANDOM AS #1
62 PRINT #1, "in;sp1;"
63 PRINT #1, "pa5900,6000;lb"; a; "x"; b; "x"; l; "wavelengths"; CHR$(3)
64 PRINT #1, "pa5900,5800;lb H-plane"; CHR$(3)
69 n = 2.4
70 pi = 4# * ATN(1#)
80 FOR i = 1 TO 180
85 theta = pi * (i - 90) / 180#
90 phi = pi / 2#
100 il# = 2# * b / pi * (pi / 2) ^ 2 * COS(pi * b * SIN(theta) * SIN(phi)) /
((pi / 2) ^ 2 - (pi * b * SIN(theta) * SIN(phi)) ^ 2)
110 a = 1 / (n - COS(theta)) * (1 - COS((n - COS(theta)) * l * pi)) + 1 / (n +
COS(theta)) * (1 - COS((n + COS(theta)) * l * pi))
120 b = SIN((n - COS(theta)) * pi * l) / (n - COS(theta)) - SIN((n + COS(theta))
* pi * l) / (n + COS(theta))
130 i2# = 1 / pi * (a ^ 2 + b ^ 2) ^ .5
140 gain(i) = LOG((COS(pi * a * SIN(theta) * COS(phi)) * il# * i2#) ^ 2) /
LOG(10#) * 10#
150 PRINT phi, i, gain(i)
160 NEXT i
165 maxgain=-300.
170 FOR i = 2 TO 179
180 IF (gain(i) > maxgain) THEN maxgain = gain(i)
190 NEXT i
200 mg = INT(maxgain)
210 PRINT #1, "pa5900,300;lb Gain in decibels (subtract ";mg;" dB)  "; CHR$(3)
2141 PRINT #1, "pa4900,890;pd;"
2142 FOR i = 1 TO 180
2143 radius = (gain(i) + 50! - mg) * 90!
2144 radius = (radius + ABS(radius)) / 2!
2145 theta = pi * (i) / 180
2146 x2% = INT(radius * COS(theta)) + 4950
2147 y2% = INT(radius * SIN(theta)) + 890
2158 PRINT #1, "pa"; x2%; ","; y2%; ";"
2159 NEXT i
2160 PRINT #1, "pu;pa0,0;sp0;"
3010 DIM a$(255)
2165 OPEN "i", #2, "c:semicirc.plt", 1
2168 LINE INPUT #2, a$
2169 PRINT #1, a$
2180 END
```

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INVOICE NO. 115278 FEBRUARY 28, 1994

04005 GENERAL NANO TECHNOLOGY
AJT ATTN: VIC KLEY
1119 PARK HILL ROAD
BERKELEY, CA 94708

PROFESSIONAL SERVICES RENDERED AMOUNT

G -59093-000 GENERAL

2/02/94	Meeting with inventor regarding developing patent strategy for inventions related to Atomic Force Microscopes.	
2/03/94	Discussion of patent applications.	
2/03/94	Reviewed inventive concepts and began developing patent strategy.	
2/04/94	Completed review of inventive concepts and development of patent strategy.	
	TOTAL FEES	1,860.00
	DISBURSEMENTS :	
2/09/94	Domestic facsimile charges.	1.50
	TOTAL DISBURSEMENTS	1.50
	G -59093-000 TOTAL:	1,861.50

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BERKELEY, CA 94708

PROFESSIONAL SERVICES RENDERED	AMOUNT
M -94005-000 PHONE/COPY/MISC. CHARGES:	
DISBURSEMENTS :	
Photocopy charges.	.20
Postage charges.	.29
TOTAL DISBURSEMENTS	.49
M -94005-000 TOTAL:	.49
TOTAL THIS INVOICE	1,861.99

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INVOICE NO. 117217 JUNE 30, 1994 PAGE 1

04005 GENERAL NANO TECHNOLOGY
AJT ATTN: VIC KLEY
1119 PARK HILL ROAD
BERKELEY, CA 94708

PROFESSIONAL SERVICES RENDERED	AMOUNT
G -59093-000	
6/09/94 redacted	
TOTAL FEES	70.00
G -59093-000 TOTAL:	70.00

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04005 GENERAL NANO TECHNOLOGY
AJT ATTN: VIC KLEY
1119 PARK HILL ROAD
BERKELEY, CA 94708

PROFESSIONAL SERVICES RENDERED — AMOUNT

A -59632-000 PATENT APPLICATION/PATENT:
A SYSTEM AND METHOD FOR
NANOSPECTROPHOTOMETRY

5/12/94	Reviewed disclosure and began preparation of application.	
5/13/94	Continued preparation of application.	
5/19/94	Continued preparation of application and prepared for meeting with Vic Kley.	
5/25/94	Meeting with Vic Kley and continued preparation of application.	
5/26/94	Continued preparation of application.	
5/28/94	Continued preparation of application.	
6/10/94	Continued preparation of patent application.	
6/13/94	Continued preparation of patent application.	
6/14/94	Continued preparation of patent application.	
6/16/94	Continued preparation of patent application.	
6/22/94	Completed preparation of first draft of patent application.	
6/29/94	Commenced preparation of second draft of patent application.	
	TOTAL FEES	5,720.00
	DISBURSEMENTS :	
6/22/94	Domestic facsimile charges.	7.50
	TOTAL DISBURSEMENTS	7.50
	A -59632-000 TOTAL:	5,727.50

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INVOICE NO. 117217 JUNE 30, 1994

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PROFESSIONAL SERVICES RENDERED	AMOUNT
M -94005-000 PHONE/COPY/MISC. CHARGES:	
DISBURSEMENTS :	
Telephone charges.	31.49
Photocopy charges.	9.10
Postage charges.	.98

TOTAL DISBURSEMENTS	41.57
M -94005-000 TOTAL:	41.57
TOTAL THIS INVOICE	5,839.07

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INVOICE NO. 117711 JULY 31, 1994 PAGE 1

04005 GENERAL NANO TECHNOLOGY
AJT 348 6TH STREET
SAN FRANCISCO, CA 94103-4788

PROFESSIONAL SERVICES RENDERED		AMOUNT
G -59093-000	GENERAL	
	DISBURSEMENTS :	
6/21/94	Patent copies.	54.60
	TOTAL DISBURSEMENTS	54.60
	G -59093-000 TOTAL:	54.60

FLEHR, HOHBACH, TEST, ALBRITTON & HERBERT
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04005 GENERAL NANO TECHNOLOGY
AJT 348 6TH STREET
SAN FRANCISCO, CA 94103-4788

PROFESSIONAL SERVICES RENDERED AMOUNT

A -59632-000 PATENT APPLICATION/PATENT:
A SYSTEM AND METHOD FOR
NANOSPECTROPHOTOMETRY

7/01/94	Continued preparation of second draft of patent application.	
7/05/94	Continued preparation of second draft of patent application.	
7/06/94	Continuation of second draft of patent application.	
7/07/94	Completed preparation of second draft of patent application.	
7/08/94	Preparation of formal drawings.	
7/12/94	Continued preparation of formal drawings.	
7/20/94	Completed preparation of third draft.	
7/21/94	Continued preparation of formal drawings.	
7/22/94	Completed preparation of formal drawings.	
7/25/94	Commenced revisions to third draft.	
7/28/94	Completed revisions to third draft and filed patent appliation.	
7/28/94	Secretarial overtime. (LaClair)	
	TOTAL FEES	4,612.50
	DISBURSEMENTS :	
7/07/94	Domestic facsimile charges.	14.00
	TOTAL DISBURSEMENTS	14.00
	A -59632-000 TOTAL:	4,626.50

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(415) 781-1989 • IRS# 94-1427764

04005 GENERAL NANO TECHNOLOGY
AJT 348 6TH STREET
SAN FRANCISCO, CA 94103-4788

PROFESSIONAL SERVICES RENDERED	AMOUNT
M -94005-000 PHONE/COPY/MISC. CHARGES:	
DISBURSEMENTS :	
Telephone charges.	21.07
Photocopy charges.	38.00

TOTAL DISBURSEMENTS	59.07
M -94005-000 TOTAL:	59.07
TOTAL THIS INVOICE	4,740.17